The Efficiency of Neural Networks to Model and Predict Monthly Mean Sea Level from Short Spans Applied to Alexandria Tide Gauge

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Contents

1. Introduction (Mean Sea Level)

- Mean sea level MSL has been considered as a stable reference datum representing the vertical datum i.e. geoid.
- MSL is required to determine the appropriate location of the engineering constructions and other activities relative to it along the coastlines.
- Sea level varies spatially due to sea surface topography and temporally due to changing of local and global meteorological conditions.
- Sea level variation or temporal variation affects shoreline and engineering works near shore.
- Sea level rise has been estimated globally to be between 10 cm and 20 cm per century

1. Introduction (Sea Level Variation)

- Sea level variation represents one of the main factors affecting the design of the coastal structures, and adopting the legal property line.
- Sea level variation leads to increasing shoreline erosion and wave overtopping, both factors contributing to failure of a structure.
- Sea level variation can be determined by using the available monthly mean sea levels and the associated meteorological data.

1. Introduction (Sea Level Status in Egypt)

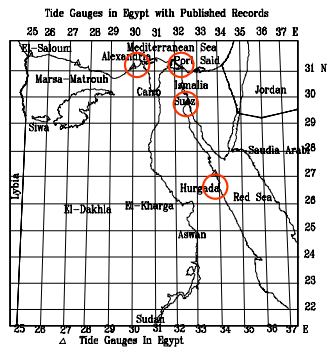


Fig.1 The distrbution of available tide gauges

1. Introduction (Sea Level Status in Egypt)

- In Egypt, the sea levels and the sea levels variations have affected many related applications. The mean sea level was established at Alexandria harbor in 1906 by taking the average of daily sea level for seven years
- Various efforts have been done to monitor the sea level variations, for the purpose of controlling the continuously increasing number of established new coastal constructions, as well as controlling the marine transportation.
- Along the coastlines of Egypt, most of the new development requires the exact information about the adopted mean sea level at the place to build safe constructions.
- Such information also helps in defining the set back line of the constructions, the property line, and the foundation level for the structures from the coastline.

Objectives

- To study the long term change of MSL at Alexandria to get an estimate for the variations of MSL along northern Egyptian coastline.
- To advise a viable technique, which would enable us to use sea level records, derived from tide gauge observations, to model and predict sea level variations.
- To use least squares technique to model and predict the variation of MSL based on sufficient available data and strong mathematical model.
- To apply the Neural Networks method compared with least squares method, by using the available monthly mean sea level data at Alexanderia tide gauge and the meteorological data for the period 1980 to 1987 at Alexanderia.

2. Modelling of Mean Sea Level Using Least Squares Technique

- The sources of sea level variations can be summarized as follows (Vaniĉek, 1978):
- 1. Atmospheric pressure variations.
- 2. Dynamic effects of sea level variations (currents).
- 3. Wind variations.
- 4. Atmospheric temperature variations.
- 5. Long periodic variations.
- 6. River discharge variations.
- 7. Changes in bathymetric configuration.
- 8. Glacial melt and crustal movements.

2. Modelling of Mean Sea Level Using Least Squares Technique

- The suggested mathematical model:

$$y(t_i) = a_1 + a_2 t_i + a_P \delta p(t_i) + a_T \delta T(t_i) + a_D \delta D(t_i) + a_{W_N} \delta W_N(t_i) + a_{W_E} \delta W_E(t_i) + \sum_{j=1}^{5} A_j \left(\cos \omega_j t_i - \varphi_j \right)$$

- where: y(ti) is the observed MSL relative to the zero datum of the tide gauge at time ti; a1 is the datum bias; a2 is the linear trend; Aj, φj are the amplitude and phase of the periodic components with frequencies ωj corresponding to the following five periods:
- 1. Annual (elliptic) tide with a period of 1 solar year.
- 2. Semiannual (declination) tide with a period of .5 solar year.
- 3. Lunar nodal tide with a period of 18.613 years.
- 4. Lunar perigee tide with a period of 8.847 years.
- 5. Chandler wave (oscillation of the Earth's poles) with a period of 435 solar days.

2. Modelling of Mean Sea Level Using Least Squares Technique

- **2.1 Data Used (Alexandria Tide Gauge)**
- Monthly mean values of sea level at Alexandria were given from Permanent Service for Mean Sea Level . The meteorological data were found to be available from the Egyptian Authority of Meteorological Observations.

Table 1 A Summary of the Main Characteristics of Monthly Mean Sea Level Data Used in This Study.

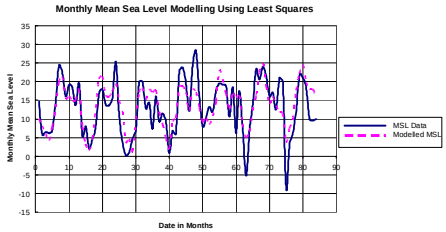
Site	Tide gauge location		Span of The time series	significant gabs	Chosen Spans
	φ	λ			
Alexandria	31° 13′	29° 55′	Jan. 1944 to Dec. 1989	Jan. 1948 to Dec. 1949	Jan. 1950 to Dec. 1989

Table 2 A Summary of the Main Characteristics of Atmospheric Pressure, Air Temperature, and Wind Data in the Present Study

site	span of the monthly time series
Alexandria	Jan. 1980 - Dec. 1986

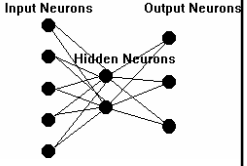
2. Modelling of Mean Sea Level Using Least Squares Technique

- The method of general least squares was applied to model the sea level variations.
- Data size was only limited for 60 records and the other data were used to test the ability of the model to predict MSL compared to original MSL.
- The mean square error MSE for this data is found to be 19 cm2 .



3. Neural Network (Basis)

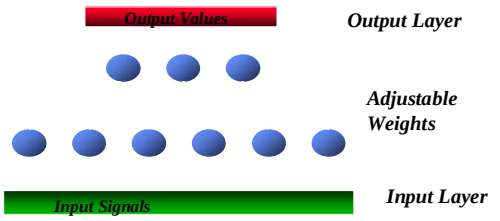
- Neural network technology imitates the brain's own problem solving process. Just as humans apply knowledge gained from past experience to new problems or situations, a neural network takes previously solved examples to build a system of "neurons" that makes new decisions, classifications, and forecasts.



- •The basic building block of neural network is the simulated neuron .
- •The network processes a number of inputs from the outside world to produce an output, the network's classifications or predictions.
- •The neurons are connected by weights which are applied to values passed from one neuron to the next.
- •A group of neurons is called a slab. Neural networks look for patterns in training sets of data, learn these patterns, and develop the ability to correctly classify new patterns or to make forecasts and predictions.

3. Neural Network (Basis)

- Neurons are also grouped into layers the input layer, the output layer. Neurons in between the input and output layers are in the hidden layer(s). A layer may contain one or more slabs of neurons.



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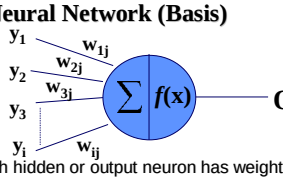
3. Neural Network (Basis)



$$\phi(x) = \frac{1}{1 + e^{-ax}}$$

- Each hidden or output neuron has weighted input connections from each of the units in the preceding layer.
- The unit performs a weighted sum of its inputs, and passed through a sigmoid activation function to determine output.
- An activation function in the output neurons should suite the distribution of the target values.
- The method of determining the weights and biases is called learning.
- The learning process requires a set of patterns "input – target output".
- During the learning process, the weights and the biases of a network are iteratively adjusted to minimize the network performance function.

3.1 Neural Network Development

- The neural networks were developed using the Neuroshell 2 neural-network development program.
- To use the program, a set of inputs and outputs must be defined, and a suitable training set must be developed.
- The available monthly mean sea level were considered as output.
- The inputs in the neural networks problem represent all the known variables that may affect the output i.e. MSL data in the current problem.
- The available meteorological data , the tides, and time were considered to be the input.
- It is advised here to choose the inputs as minimum as possible and to study the effect of removing the non- significant inputs.
- The data in neural networks are categorized into three sets i.e. training or learning set , test set, and production set.

3.1 Neural Network Development

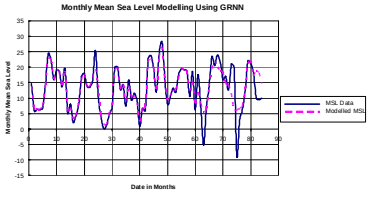
- The learning set is used to determine the adjusted weights and the biases.
- The test set is used for calibration, which prevents overtraining networks.
- The test set should be approximately 10 to 40 percent the size of the training set of data
- The production set may be used to test the network's result with data the network has never seen before.
- The MSL records (84 months) were divided into three sets.
- The first set with 60 records was used as training set,
- the second test with 6 records was used as test set,
- while the third set with 18 records was used as production set.
- The Neuroshell 2 program offers several types of learning concepts.
- Among them are the back-propagation networks. Back-propagation networks are a supervised type of network, i.e. trained with both inputs and output.

3.1 Neural Network Development

- The General Regression Neural Networks GRNN models, as learning model, can provide estimates of continuous variables, and converge to the underlying regression surface.
- This type of network can be used for any regression problem in which the assumption of linearity is not justified.
- For the current case, normal three-, four-, and five-layer back-propagation networks were tested. Three-, four-, and five-layer back-propagation models were also developed that had jump connections between layers. A GRNN model was also developed. Overtraining of neural networks is possible. The Neuroshell 2 program provides an automatic feature to save the network that minimizes the error of the test set.

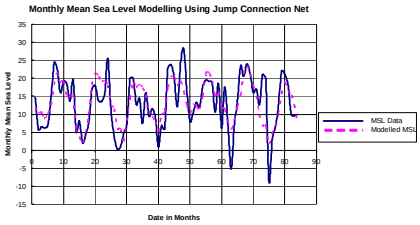
3.2 Neural Network Results

- The data sets were examined using all the neural networks method offered by neuroshell2 the results of the best six models are illustrated
- The modelled MSL versus Measured MSL is presented for only two models. Fig. 3 indicates the results of GRNN model which shows close values between the modelled and measured MSL for the train and test sets and small deviation for the production set.
- The mean square error estimated for this model is minimum compared with the other models which indicates that this model is best to model and predict MSL.



3.2 Neural Network Results

- Fig. 4 shows the results of Jump Connection Net compared to measured MSL.



3.2 Neural Network Results

- The results of the Standard Net, Multiple Hidden Slabs (Ward net) 5 Layers, Multiple Hidden Slabs (Ward net) 4 Layers, and Recurrent Networks with Dampened Feedback methods show the same characterstics as GRNN method. The modelled and predicted MSL resulted from these models match with the measured MSL. The mean square errors are shown in Table 3.
- The GRNN metod is the more effective method in model and predict MSL.

Table 3 Mean Square Error MSE Estimated for Each Model

Model	MSE
Least Squares	19
General Regression Neural Networks	11.9
Jump Connection Net	21.9
Standard Net	16.5
Multiple Hidden Slabs (Ward net) 5 Layers	12.16
Multiple Hidden Slabs (Ward net) 4 Layers	12.1
Recurrent Networks with Dampened Feedback	14

4. Conclusions

- The mean sea level along the coastlines is variable from place to place and from time to time, according to the change in the weather conditions, temporal variations, and Sea Surface Topography SST influences.
- Accordingly, MSL can not be used in different applications without considering the main sources of its variations.
- The long period variation of MSL should be taken into consideration during the design, construction , and maintanance of Coastal Structures.
- These long period variations may be modelled with sufficient records of sea levels taken at a certain tide gauge using e.g. Least squares method.
- In case of insufficient data records for sea levels the least squares does not give accurate results.

4. Conclusions

- The availabe MSL data for seven years at Alexanderia associated with the avilable meteorological data were used to model and predict MSL.
- The mathimatical model of the sea level variations was used and the estimated mean square error from least squares results is 19 cm2 .
- The neural network methods were applied for the MSL at Alexanderia as output data while the meteorological data and tide effect were considered as inputs.
- The data were trained by different methods. The method of general regression neural networks gave mean square error 11.9 cm2 .
- The other method of training show reasonable values better than least squares except Jump Connection Net.
- It is recommended to Use GRNN method to model and predict MSL.